ECI Symposium Series, Volume RP5: Proceedings of 7th International Conference on Heat Exchanger Fouling and Cleaning - Challenges and Opportunities, Editors Hans Müller-Steinhagen, M. Reza Malayeri, and A. Paul Watkinson, Engineering Conferences International, Tomar, Portugal, July 1 - 6, 2007

MILK PROTEIN FOULING IN A TUBULAR HEAT EXCHANGER: EFFECT OF MILK TEMPERATURE AND REYNOLDS NUMBER

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ABSTRACT

In the present work, β-lactoglobulin fouling phenomenon was studied, when milk flowed in a tubular heat exchanger, where hot water was used to raise milk temperature. Experiments have been carried out to determine the effect of Reynolds number and fluid temperature in whey protein fouling, in a tubular heat exchanger and the results showed that fouling increases as the fluid temperature increases. In addition, as the Reynolds number increases, the total amount of fouling (obtained by integrating the whole amount of deposit down the tube dividing by the total area) decreased.

Key-words: fouling, solubility, β-lactoglobulin.

INTRODUCTION

Milk is a complex mixture, constituted by a composed emulsion of fat and a colloidal protein dispersion, with lactose solution. Such constituents are complemented by minerals (mainly calcium), vitamins, enzymes and organic composites (Kon, 1972, Torii et al, 2004, Magalhães and Telmo, 2006).

When used for commercialization, milk becomes a product greatly perishable, that is, its liquid state and its nutritional composition becomes susceptible for microorganisms proliferation, those originally in milk or that introduced by manipulation (Martins et al, 2007). implicating in which provokes the reduction of processing efficiency"

For that reason, since 1966 the pasteurization became mandatory in dairy products. However, an important problem in pasteurization is fouling, which provokes the reduction of processing efficiency, bombs overloading, the periodic machine stopping for cleaning and even its substitution. Due to those reasons, it is reasonable that heat exchangers efficiency should be evaluated in order to recognize the situations that promote efficiency losses. The detection and quantification of fouling deposits in the wall is one of the techniques to evaluate their performance (Veisseyre, 1972; Afgan & Carvalho, 1998).

Fouling is an important problem in many heat exchangers, that requires careful monitoring and in spite of precautions taken in the design of the heat exchanger, fouling is an unavoidable problem (Belmar et al, 1993, Afgan & Carvalho, 1998, Pelegrine & Gasparetto, 2004).

Fouling in food industry is a severe problem compared with other industries. For example, while in the petrochemical refineries, heat exchangers may only be cleaned annually, in the dairy industry it is common practice to clean every 5-10 hours (Murray & Deshaires, 2000).

The problem manifests itself economically through loss of efficiency of the heat exchanger, in time and materials required to clean fouled surfaces, in loss of product, and through losses of vitamins, minerals, and other nutrients in the foul layer. Besides, the fouled material joined the wall allows microorganisms adhesion. The fouling phenomenon is the consequence of protein deposition, which was previously denatured and joined in the hottest areas of the heat exchangers surface. When the temperature of the protein solution is raised high enough for a given time, the protein is denatured. Proteins are denatured by the effect of temperature on the non-covalent bonds involved in stabilization of secondary and tertiary structure, for example, hydrophobic, electrostatics and hydrogen bindings (Petermeier et al, 2002).

Milk fouling deposits consist of a layer of protein aggregate and minerals which can be several millimeters thick. Deposits formed at temperatures below 110°C contain approximately 50-60% protein and 30-35% minerals. Half of the protein deposit is β-lactoglobulin. Below about 70°C β-lactoglobulin forms an adsorption layer on the heat transfer surface of less than 5 mg/m^2; however, on heating above 65°C, it becomes thermally unstable. Two types of reaction occur sequentially. The protein first partially unfolds, in molecular denaturation denaturation, exposing reactive sulphydryl (-SH) groups, and then polymerises in intermolecular aggregation, either with other β-lactoglobulin molecules or with other proteins such as α-lactalbumin (Belmar-Beiny et al, 1993, Belmar-Beiny & Fryer, 1998).

EXPERIMENTAL PROCEDURE

The apparatus schematic diagram is shown in Fig.1. The heat exchanger used consists of a tubular heat exchanger, constructed in Food Engineering Laboratory, in Agronomy

Science Department, according to project considered for e 1.

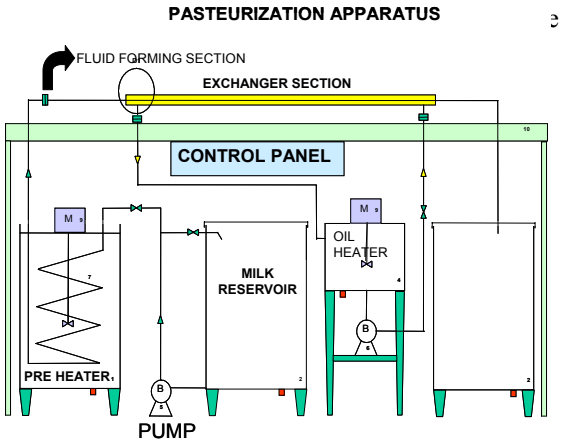

Figure 1: Pasteurization plant.

The pre heater consisted of a 30 m coil of ½ pol. copper tubing mounted in a large drum filled with water. Temperature was regulated with an external controller.

In heater section a thermal oil (at 83 or 95ºC, depending on milk temperature exit) was used to provide hot fluid for the countercurrent heat exchanger. A high oil flow rate of 50 liters/min was used to maximize the heat transfer coefficient from the oil to the tube. The milk and oil inlet and outlet temperatures were measured by digital thermocouples (Omron, E5CN model), placed in entrance and exit heat section.

Raw milk (Whole) was received in a tank where it was pumped to preheating section and, after finished the process, the pasteurized milk was collected in another steel tank .

Table 1: The composition of raw milk is listed in table above:

COMPONENT	%
PROTEIN	3,3
FAT	3,9
CARBOIDRATE	5,0
ASH	0,7
WATER	87,1

Prior to fouling, the stainless steel tubes were cleaned for 30 minutes at 45°C with a 1% (v/v) detergent to remove any oil deposit on the surface resulting from the manufacture. Milk was passed through the pre heater to ensure correct inlet temperature.

At the end of a run, the fouled tube was removed and carefully cut into 5 cm lengths, using a pair of scissors. Test sections were dried overnight and then weighed. Continually, the fouled deposition was removed from the tube wall. Each tube of 5 cm lengths was cleaned by brushing with hot water and detergent; this procedure was followed until all inside surface was clearly cleaned. The cleaned tube was weighed and the fouling results were expressed in terms of protein grams per unit area.

Experiments have been carried out to determine the effect of Reynolds number and fluid temperature in whey protein fouling, in the heat exchanger. Previously, the centrifugal pump mass flow was adjusted in order to get laminar flow (Reynolds number of 1800) and the preheater and oil heater thermocouples temperature was adjusted in order to get 70 or 80°C for milk outlet temperature. Continuously, for each milk outlet temperature, the centrifugal pump frequency was adjusted in order to get different mass flow and, consequently, different flow types (transient or turbulent).

RESULTS

Experiments were conducted in which milk outlet temperature varied from 70°C to 80°C, for a constant fluid Reynolds number 1800 and a tube length of 1.8 m.

The temperature profile of the milk along the channel is in the table above:

Table 2: Milk temperature profile along the tube length.

REYNOLD	HEAT EXCH. INLET	HEAT EXCH. AT 0,5 m	HEAT EXCH. AT 1,0 m	HEAT EXCH. OULET
3700	62°C	64,3°C	67,5°C	70,4°C
7200	60°C	63,7°C	68,2°C	70,8°C
1800	70°C	72,8°C	76,8°C	80,5°C
3700	66°C	74,6°C	78,6°C	81,2°C
7200	64°C	73,5°C	77,2°C	80,4°C

The time necessary to process 250 liters of milk as different, for each mass flow. The table above presents the processing data, for each temperature and type of flow.

Table 3: Process time, at different temperatures and flow tipes.

FLOW CONDICTIONS	LAMINAR	TRANSIENT	TURBULENT
70ºC	9,5 hours	6,5 hours	3,5 hours
80ºC	11,0 hours	7,0 hours	3,5 hours

The results are represented in Figure 8 that shows that the total amount of deposition increases with milk outlet temperature. At 70°C, although the fouling is at low level in the inlet region, it increases significantly at some point down the tube.

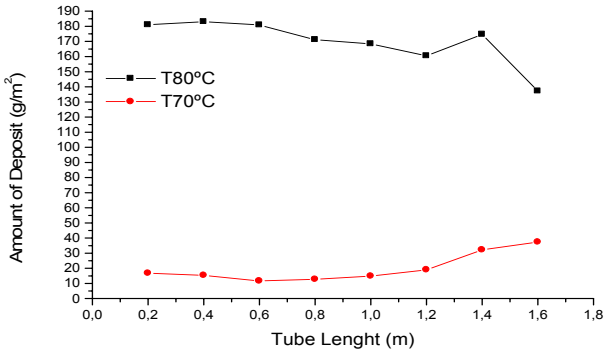

Figure 8: The effect of milk temperature on whey protein fouling.

At 80°C the deposition was more accentuated in the inlet area than in outlet. These results confirm Pelegrine and Gasparetto (2004) observations, indicating that, in this temperature, the fouling process may be mass transfer controlled. This is probably due the fact of, the milk critical temperature is in the range 70°C and when the bulk fluid exceeds this temperature, the fouled deposits increase about two orders. When milk outlet temperature was 70°C, at inlet area, the product was already at 60°C; therefore, the deposition was more accentuated in outlet area.

When milk outlet temperature was 80°C, at inlet area the product already was at critical temperature. Therefore, the deposition was more accentuated in the inlet area, because in that region the protein concentration was higher.

From figure 8 it has been that experiments under the conditions described above produce significant increases in fouling as milk temperature is higher. Consequently, the fouling is faster when milk temperature is higher.

The fouling process also could be noted with mass flow decreasing, during milk processing. The mass flow was obtained by measuring the time of milk to occupy a 1 liter recipient, weighing the product and dividing this mass by the time. At 70°C the mass flow decreased along milk processing, from 0.00974 to 0.0062 Kg/s (36% reduction in mass flow). At 80°C this decreasing was 47%, along the pasteurization processing.

Experiments were also conducted in, at two different Reynold number: 3700 and 7200, with milk outlet temperature of 70°C. Figure 9 shows two representative results of the effect of different Reynolds number on the amount of protein deposition. From figure 9 it can be observed that as the Reynolds number increases, the difference between the amount of fouling at the inlet and outlet becomes greater. In addition, as the Reynolds number increases, the total amount of fouling (obtained by integrating the whole amount of deposit down the tube and dividing by the total area) decreases. This occurs because in turbulent flows the fouling cleaning rate is greater, resulting in less fouling deposits.

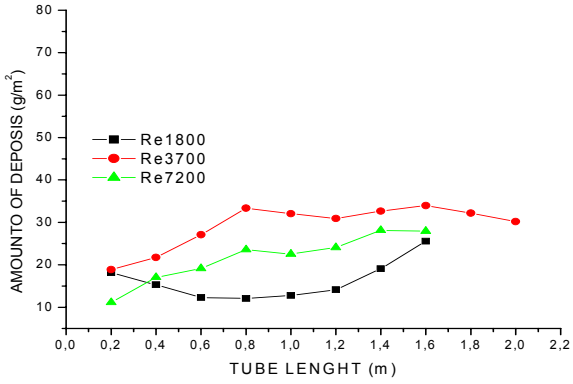

Figure 9: The effect of Reynolds number on whey protein fouling.

The results in figure above confirm Hegg et al (1985) and Jeurnink et al (1996) observations. In laminar flows (Reynolds number of 1800) the fouled proteins are more fixed because the subsequent flux is slower and then unable to remove the fouled proteins.

CONCLUSIONS

From the results it can be concluded:

1. Fouling is influenced by fluid temperature and Reynold number.
2. The fouled deposits were distributed randomly over the surface and result in fluid being convected to and from the bulk.

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